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Luminescence enhancement of fluorescent SiC via surface nanostructuring produced by 2-step cost effective method

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Suppression of total internal reflection loss, arising from the abrupt refractive index difference at the interface between materials and the surroundings, is critical for LED applications. Donor-acceptor doped fluorescent SiC has been approved as a highly efficient wavelength conversion material with high color rendering index and long lifetime [1-3]. However, SiC has a quite high refractive index of 2.6, so it is important to enhance the light extraction efficiency. Antireflective subwavelength structures (ARS), inspired by moths, can result in broadband suppression of reflection and consequently increase the light extraction efficiency [4, 5]. Several technologies have been used in order to fabricate ARS, although most of them deploy nano-pattern definition and etching. Nano-pattern definition can be achieved by various techniques like nanosphere lithography [6], electron-beam lithography [5], and block copolymer micelle nanolithography [7]. However, such techniques make the fabrication process either expensive or time consuming, thus limit the potential for large scale applications.

In this work, we report a method to fabricate nanostructures where the nano-pattern is formed during etching. The method is simple and cost effective. The fabrication flow consists of two steps (see Fig. 1). It deploys a thin layer of aluminum (Al) which is deposited on top of a SiC surface. Then reactive ion etching (RIE) is performed with a mixture of CF_4 and O_2 gases. During the RIE the Al layer is attacked by ion bombardment and is discontinuously eroded, while the SiC surface is etched, when exposed to the plasma. The non-sputtered Al film acts as hard masking material, together with micromasking. The micromasking can be native oxide on the SiC surface or it can be generated through the process. Sputtered Al particles are the main source of micromasking. Furthermore, fluorine and oxygen chemically react with Al particles and form non volatile species that locally mask the SiC surface. The presence of fluorine and carbon can result in the formation of fluorocarbon polymer that is known to act as micromask in black silicon fabrication. The residual masking can be removed by using heated phosphoric acid solution and ultrasound. The resulting ARS exhibits a characteristic stochastic landscape (see Fig. 2) which can be partially controlled by changing the Al thickness and the RIE conditions.

The photoluminescence intensity, after applying the stochastic landscape on the fluorescent SiC surface, is significantly enhanced (210%) at an emission angle of 10°, in the wavelength range of 450-750 nm (see Fig. 3). Moreover, from angle resolved luminescence measurements, it was found that the luminescence could be enhanced by more than 106% in a very large emission angle range, up to 70° (see Fig. 4). The luminescence enhancement decreases with the emission angle, for 80° the value reported is 78%.

In conclusion, a simple 2-step, cost effective method for fabricating nanostructures on SiC has been demonstrated. The method takes advantage of the combinatory hard masking and micromasking. By applying the stochastic landscape on fluorescent SiC, the luminescence intensity was significantly enhanced for a wide emission angle range. The method could be applied on diverse materials.

[1] S. Kamiyama, T. Maeda, Y. Nakamura, M. Iwaya, H. Amano, I. Akasaki, H. Kinoshita, T. Furusho, M. Yoshimoto, T. Kimoto, J. Suda, A. Henry, I. G. Ivanov, J. P. Bergman, B. Monemar, T. Onuma, S. F. Chichibu, J. Appl. Phys. 99 (2006) 093108.
[2] Y. Ou, V. Jokubavicius, S. Kamiyama, C. Liu, R. W. Berg, M. Linnarsson, R. Yakimova, M. Syväjärvi, H. Ou, Opt. Mater. Express 1 (2011) 1439–1446.
[3] M. Syväjärvi, J. Müller, J. W. Sun, V Grivickas, Y. Ou, V. Jokubavicius, P. Hens, M. Kaisr, K. Ariyawong, K. Gulbinas, P. Hens, R. Liljedahl, M. K. Linnarsson, S. Kamiyama, P. Wellmann, E. Spiecker, H. Ou, Phys. Scr. 2012 (2012) 014002.
[4] Y. Ou, V. Jokubavicius, R. Yakimova, M. Syväjärvi, H. Ou, Opt. Lett. 37 (2012) 3816-3818.
[5] Y. Ou, V. Jokubavicius, P. Hens, M. Kaiser, P. Wellmann, R. Yakimova, M. Syväjärvi, H. Ou, Opt. Express 20 (2012) 7575–7579.
[6] C. H. Sun, P. Jiang, B. Jiang, Appl. Phys. Lett. 92 (2008) 061112.
[7] Y. R. Brunner, B. Keil, C. Morhard, D. Lehr, J. Draheim, U. Wallrabe, J. Spatz, Appl. Opt. 51 (2012) 4370-4376

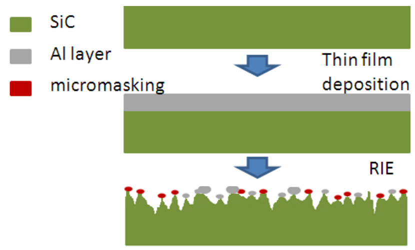

Figure 1. Schematic illustration of the stochastic ARS fabrication flow

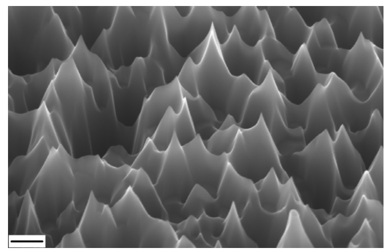

Figure 2. A scanning electron microscope image of the nanostructured surface (tilt 45°). The scale bar is 200nm.

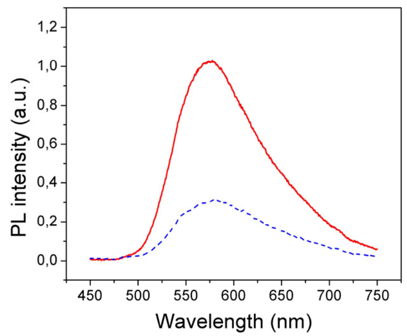

Figure 3. Luminescence spectra of the fluorescent SiC with (continuous-red curve) and without (dash-blue curve) stochastic nanostructures at an emission angle of 10°.

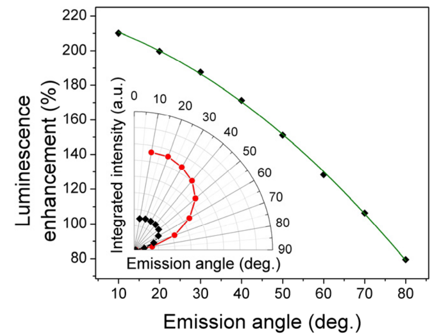

Figure 4. Luminescence enhancement of fluorescent SiC at different emission angles, after applying stochastic nanostructures. Inset: Spatial emission pattern for non-structured fluorescent SiC (black curve) and nanostructured fluorescent SiC (red curve).